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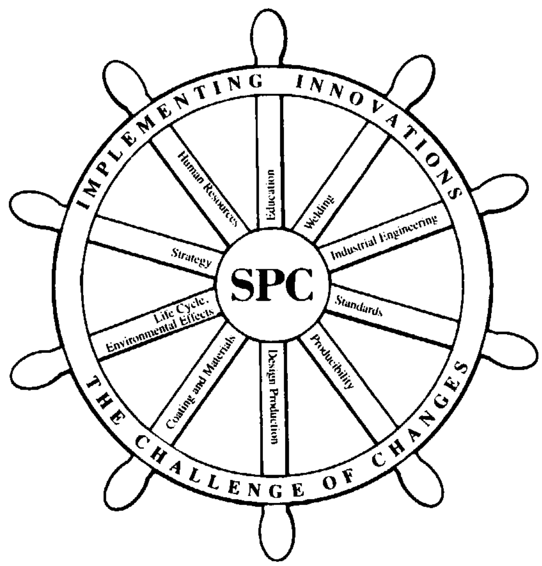

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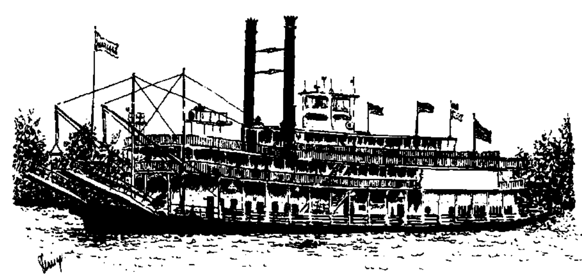

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Measurement of Shipboard Piping Using a Portable Coordinate Measuring Machine (PCMM)

No. 7A-3

James E. DeFoor, Visitor, (to be presented by E. Earl Wilson, Visitor, Norfolk Naval Shipyard)

ABSTRACT

This paper describes available technology for a Portable Coordinate Measuring Machine (PCMM) which can be hand carried onboard naval vessels. The PCMM can perform measurements in confined spaces throughout a vessel on pipes, tubes and assemblies, as well as their end fittings and support devices. Al though portable, the PCMM can also be used in a stationary position for repetitive measurements.

The PCMM is composed of four major components: an articulated six- axis digitizing arm, control unit, contact and non- contact probes, and tube and surface three-dimensional measurement software. The PCMM arm, lightly constructed, duplicates the articulation and reach of the human arm elements (shoulder, elbow, and wrist). various contact and non-contact measuring probes attach easily to the wrist of the machine.

The PCMM control unit performs all the necessary mathematical and geometric calculations without the use of external computers or templates. It also contains sufficient data memory so that the operator is able to measure and Inspect geometric features such as points, lines, planes, arcs, circles, spheres, and cylinders, as well as defined surfaces along lofting lines, and complex surfaces at coordinate points.

BACKGROUND

The design of a ship includes an infinite variety of unusual shapes and configurations to which the piping systems must adapt. The miles of pipe running throughout ships must be constructed, assembled and fitted to go around, over, under and through ship's components. They must also be placed so as not to interfere with the operations and maintenance of machinery, doors, hatches or openings. Therefore, it is necessary for piping systems to contain hundreds of bends and fittings. In addition, the design and placement of pipe helps absorb the stresses and strains placed on the pipe when the ship is in motion.

If pipefitters used only straight lengths of pipe, making a bend would require hundreds of different fittings, a situation which would not be practical. Accurate measurements for bending pipe are critical if the pipe is expected to fit and function correctly. Proper fit reduces the chance for leaks and equipment failure due to leaks. Hence, correct and accurate pipe measurements for pipe bending can reduce rework and cost.

Present Measurement Method

The following is a brief description of a typical manual method for measuring pipe aboard a naval vessel by naval shipyard personnel. Although there are many major elements involved in replacement of shipboard pipe (i.e.. measuring, templating, cutting, end prepping. bending, fitting-up, purging, and welding), this paper deals only with measurements and how the measurements are used to bend pipe.

After a pipe replacement job has been identified, a pipefitter completes the following tasks: reviews the job order, reviews blueprints (if available) of the pipe section that is to be replaced, plans his or her work, gathers the necessary tools (ruler. framing square, protractor, calculator, sketch paper, and pencil), and goes to the ship to commence the job.

The pipefitter determines the location of the pipe to be removed from the job order. For this particular case, the pipe will remain attached until the new replacement pipe is manufactured and ready for installation.

The blueprint does not always specify, identify or give dimensions of the section of pipe to be replaced. Therefore, the pipefitter must prepare hand sketches of the pipe and determine the exact dimensions within l/16 of an Inch.

In the example below, the section of pipe to be replaced is determined to have two bends and a rolling offset as shown in Figure 1. The exact location of the end cuts, if not specified, are determined by the piping engineer, foreman and pipefitter. A

Pipe Sketch

The pipefitter must prepare a sketch to tell the pipe bender precisely how the pipe is to be shaped. The views needed are Plan. elevation, and right side as shown in Figure

2. Dimensions and calculations are measured and calculated to the center line of the pipe.

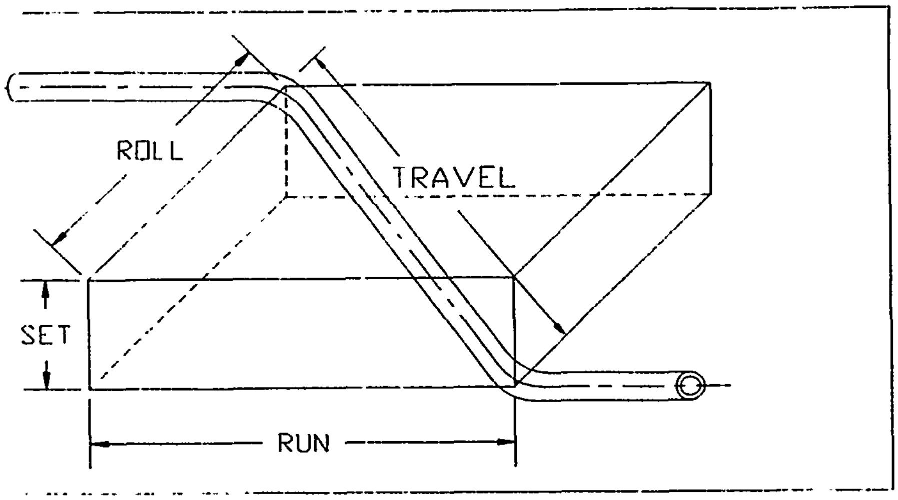


Figure 1. Run, Set, Roll, and Travel

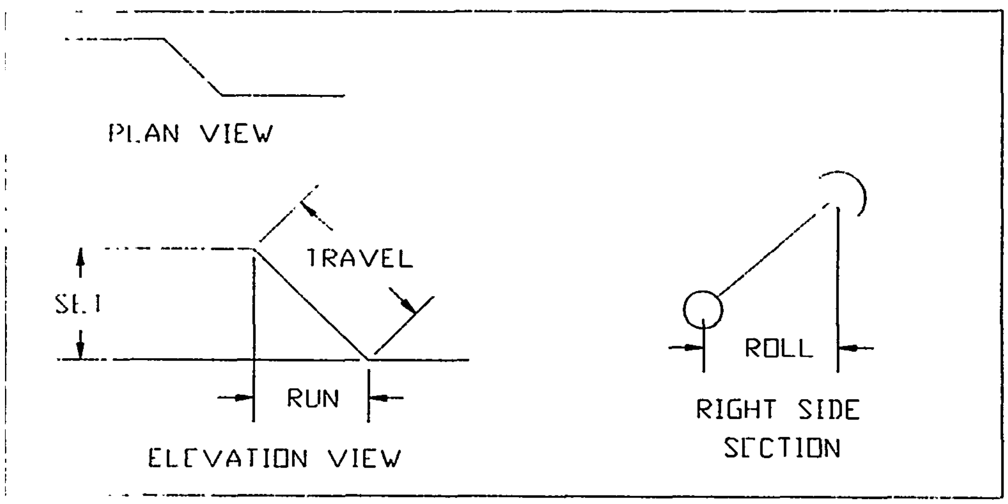


Figure 2. Typical Pipe Center Line Sketch

<u>Measurement and Calculations</u>

The kinds of measurements and/or calculations required by the bender in accordance wlth reference (2) are as follows: set, run, radius of the bend, angle of the bend, roll, travel, and true end- to-end length. A modification of the Pythagorean Theorem is used to calculate the true distance (travel) between bends for a rolling offset.

$$H = a^2 + b^2 + c^2 \qquad (1)$$

where H = travel
a = run
b = set
c = roll

Actual measurements with rules and framing squares are determined to l/16 inch. Calculations are rounded to the nearest 0.254 mm (0.01”). Measurements and calculations are made to the center line of the pipe. Actual dimensions shown on sketches are in fractions to the nearest 1.587 mm (1/16”).

True length (end-to-end) is needed to determine the amount of material necessary to bend the piping run and to ensure proper fit-up. The total length (end-to-end) for a bend is determined by subtracting twice the cut-off (Co) from the plan length (PL) and adding the distance around the bend (DAB).

$$\text{True length (end-to-end)} = PL - 2(CO) + DAB \qquad (2)$$

The information needed from a bend is identified in Figures 3 and 4.

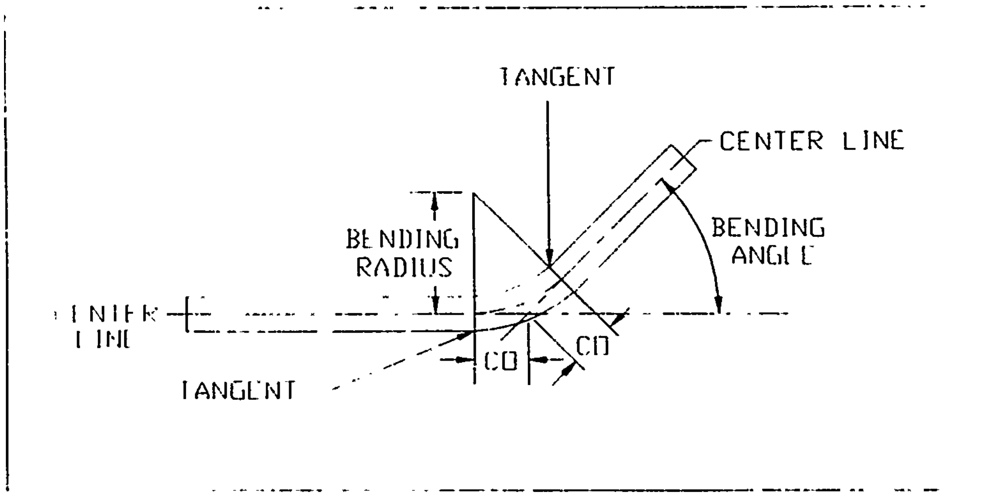


Figure 3. Features of a Bend

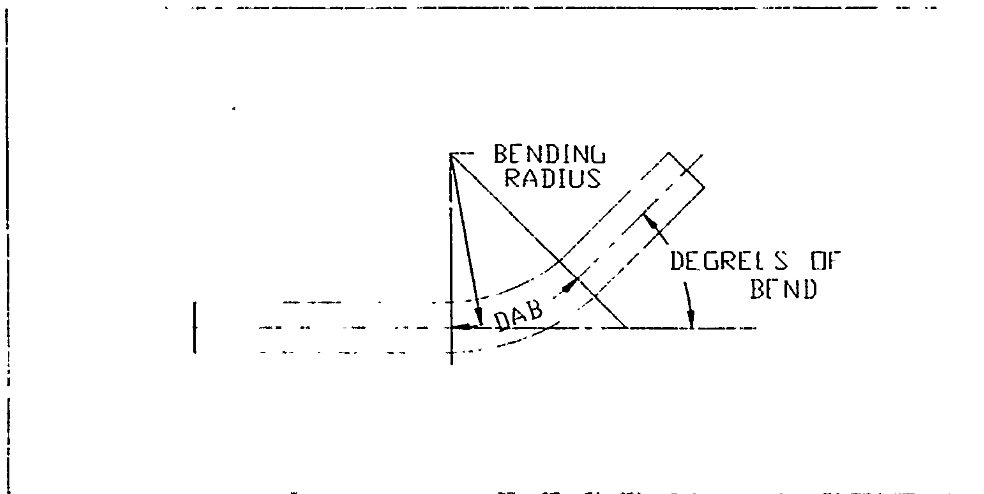


Figure 4. Distance Around a Bend (DAB)

The equation for finding the length of a cut-off (CO) is:

$$CO = C \times R \qquad (3)$$

where C = numerical value which changes according to the bending angle or degrees of bend
R = bending radius

The two most common bend radii used at Norfolk Naval Shipyard (NNSY) are 3D and 5D; 5D is preferred.

The equation for finding the distance around a bend $_{(DAB)}$ is:

$$DAB = D \times R \times 0.01745 \qquad (4)$$

where 1) number of degrees in bending angle,
R 2 bending radius in degrees
0.01745 = numerical constant in radians/degree

The value 0.01745 radians is the length of 1 degree of arc.

A

Segments of the plan length (PL), Fiqure 5. may be measured, calculated or given.

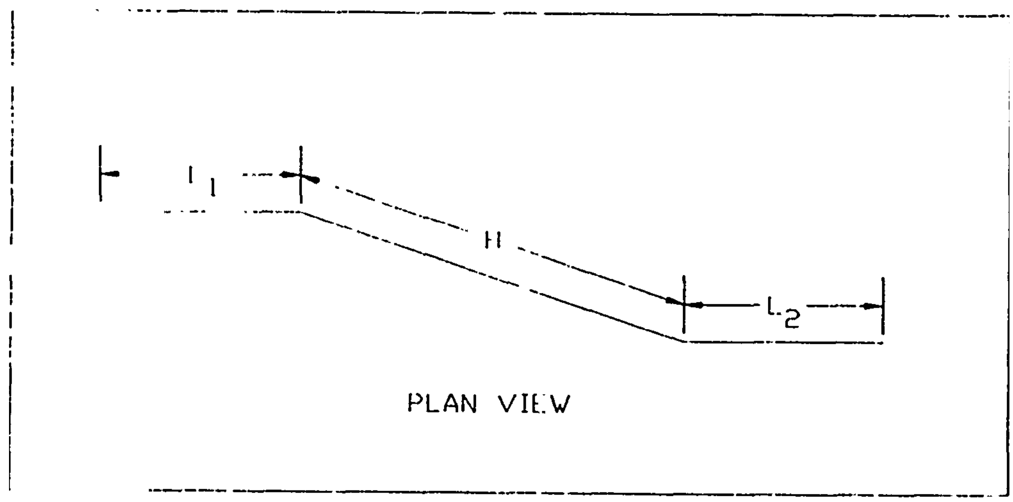
The formula for determining the plan length for Figure 5 is:

$$PL = L_1 + H + L_2 \qquad (5)$$

where PL = plan length
L_1 = length of pipe from cut off to firsl bend
H = travel
L_2 = length of pipe from second bend to cut off

The true length (end to end) is calculated using the formula:

True length (end- to end) = PL 2(CO's) first bend - 2(CO's) second bend 1 DAB first bend + DAB second bend.



Flgure 5. Plan Length

After the sketch has been completed and all required dimensions are determined and checked, the sketch is ready for the pipe bender. The sketch may be re checked by a piping engineer or a foreman or given directly to the bender. The pipe is then manually bent.

The manual method of pipe measurement is labor intensive and is susceptible to errors in measurement and calculations. Errors lead to rework and increase the labor and material cost of the pipefitting process.

DISCUSSION

Manual measurement of shipboard pipe has not changed much in decades. The wooden six foot folding rule and the framing square are still the basic tools of the trade. The slide rule has given way to the hand held calculator for performing calculations. Efforts are underway to design ship systems using Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) Systems, which will provide more accurate drawings and dimensions if the configuration data and drawings represent "as built" systems and are updated as changes are made. lt remains to be seen whether or not CAD/CAM designed ships and ship's systems will improve the measurement of pipe spools or pipe systems to be replaced.

Proposed Pipe Measurement Method

A new measurement tool (new to shipboard pipe measurement) has recently been introduced, the Portable Coordinate Measuring Machine (PCMM). The PCMM is presently being used in the aircraft automotive and medical fields with excellent measurement results. Tubing, sheet metal parts, subassemblies and various surface configurations are measured and digitized. The digitized X, Y and Z coordinates can be uploaded to CAD systems and downloaded to computer Numerical Controlled (CNC) machine work stations for manufacturing.

This paper will describe the manipulation of a PCMM In general terms, and will not attempt to explain the design of the equipment or development of the software.

PCMM Measurement Demonstration

Recently a PCMM was successfully demonstrated in the pipe shop at the shipyard. A piping run was measured by digitizing the x. y, and z coordinates and then the coordinates were downloaded into a CNC pipe bender. on command, a pipe spool was bent automatically to the coordinates previously measured.

The pipe measurement demonstration was performed three times. Each time the PCMM generated x, y, and z coordinate data which was downloaded to a CNC pipe bending machine. The bent pipe produced by the bending machine was indeed an accurate representative of the pipe measured.

Description of PCMM

The PCMM demonstrated at the shipyard consists of four major components.

1. An articulated arm which has the same shoulder, elbow, and wrist movements as the human arm.

2. A control unit (lap top PC) which has all the necessary mathematical and geometric operations and contains sufficient data memory that the operator is able to measure features such as points, lines, planes, arcs, circles, spheres, and cylinders as well as define surfaces at coordinate points without the use of external computers.

3. Contact and non contact probes.

4. Tube and surface three dimensional measurement and calculation software.

PCMM Measurement

Figure 6 represents a pipe configuration similar to the configuration used to illustrate and dcscribe manual pipe measurement . This configuration is also similar to the actual pipe spool used for the PCMM test and

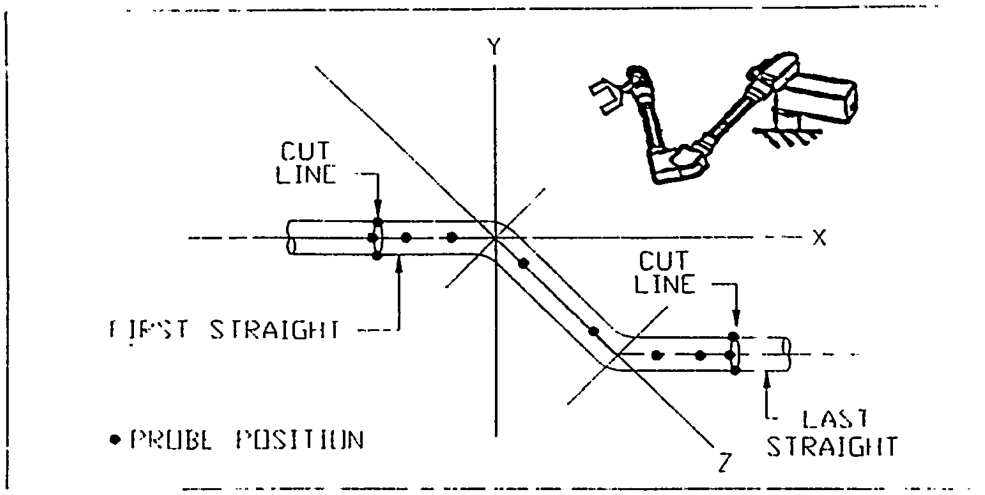


Figure 6. Typical Pipe Configuration Measured by PCMM

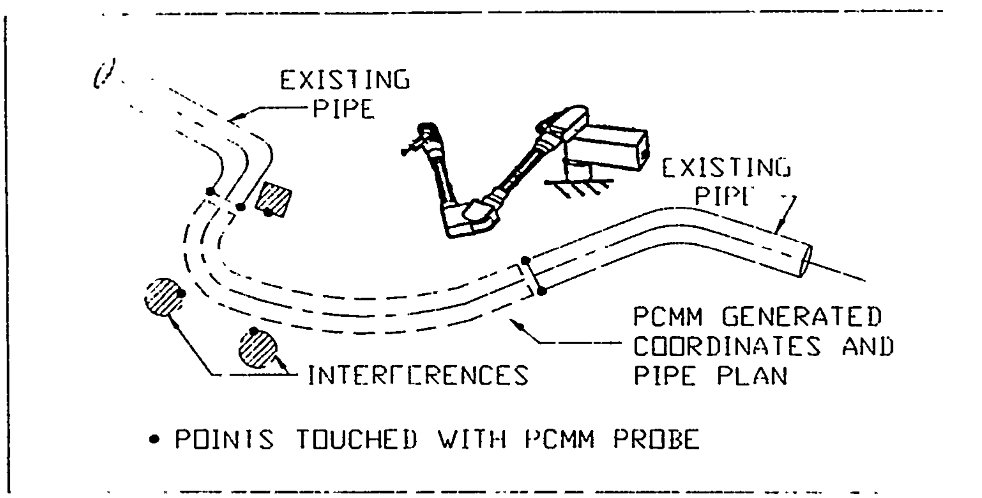


Figure 7. PCMM Generated Pipe Design

evaluation at the shipyard. A method for measuring and digitizing the x, y, and z coordinates of the pipe spool for replacement is described below.

The measurement is performed using a non-contact, light beam probe. The measurement is started at the designated end cut on the first straight, as shown in Figure 6. The pipe is measured as a “new part” by measuring two points per straight. The length of each straight is automatically calculated after “new part” measurements are completed.

The bend radius of each bend is determined from measurements of the adjacent straights to the bends and from the x, y, z coordinates spacial relationship of the straights. The PCMM software also automatically calculates the end- to- end length of the desired replacement pipe.

The specially designed and developed PCMM software manipulates the data and generates x, y, and z coordinates for the pipe diameter, pipe end cut lines, bend angles, rolling offset, bend radii, and end to end length of the replacement pipe. The data is then downloaded into a CNC pipe bender and a pipe spool is bent automatically. The data may also be uploaded into a personal computer (PC) with CAD capabilities to produce the necessary pipe drawings.

Figure 7 represents the new piece of pipe measured with a PCMM and designed to a “best fit” arrangement by the PCMM software during the second series of PCMM tests and evaluations.

Using a ball point probe for surface contact, one end of the cut pipe is touched to measure and digitize the x, y, and z coordinates of the end cut. Then the probe is moved to the inter ferences where the surface of each obstruction is touched and the x, y, and z coordinates digitized. The probe is then moved to the other pipe; that pipe end is probed, and x, y, z coordinates are generated.

The specially designed and developed PCMM software manipulates the data and generates x, y and x coordinates, pipe diameter, pipe end configuration, bend angles, bend radius and the end to end length **of the** required pipe spool to get the best Eit through and around the interferences. This design data can be downloaded into a CNC pipe bender **where a pipe section** can be bent. In addition, the data can be uploaded into a PC with **CAD** capabilities to produce pipe drawings.

Two such tests were performed with excellent results.

CONCLUSIONS

Five demonstrations **of** measurement tests do not necessarily prove that the PCMM is the final answer to all pipe measurement. But the tests strongly indicate that a PCMM might provide a significant breakthrough in automated pipe measurement and bending. Measurement by PCMM and bending by CNC vine bending machines could reduce vine measurement and bending time from shifts to hours. Additonal tests are needed in a shipyard environment, aboard ships, and in confined spaces to determine the exact value of the PCMM.

The shipyard prepared a Naval Repair Technology Project Brief that described a PCMM and its potential **for cost** reduction. The Project Brief was approved **for** the requested funds to procure a PCMM for **further testing** and evaluation. A PCMM is expected to be available for testing and evaluation prior to this paper being presented at the 1992 Ship production symposium.

Pertinent information regarding any new tests and evaluations will be addressed at the Symposium.

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